The current mirror as shown in FIG. 6 is preferably powered via the node D1 for connection between the circuit and the load L1.

The gate terminal of the transistor T1 is also coupled to ground through a resistive load R1. The load R1 shown represents schematically one or more resistors in series. A driver circuit, illustrated in FIGS. 4 and 5 by the block C1 and also acting on the gate terminal DR1, is omitted from FIG. 6.

The operation of the circuit in FIG. 6 during the recycling phase will now be described.

When the driving transistor T1 is turned off by the driver circuit, the transistor T1 is again turned on for recycling upon the excess voltage on the node D1 reaching the value VmaxD1, which corresponds to the conducting state of the diode DI1. As can be seen in the Figure, this value is given by the relation VmaxD1=Vref+VDI1+Vbe(Q11), where VDI1 is the voltage drop across the diode DI1 in conduction and Vbe(Q11) is the potential difference between the base and the emitter of the transistor Q11, as connected in a diode configuration. The value of Vmax is approximately equal to the value of Vref with the diode DI1 and current mirror conducting. In this condition, the diode DI1 will actually be conducting because a voltage is present between its anode and cathode terminals which is equal to the forward biasing voltage. A current is caused to flow through the input leg of the current mirror Q11–Q21, from the potential reference through the diode DI1, which is mirrored onto the output leg. Thus, the current mirror supplies current to the resistor R1 and turns on again the transistor T1, biasing its gate DR1.

In a condition of no recycling, such as when the transistor T1 is on and a current is flowing through the load L1, the diode DI1 functions to block the current flow, the drain terminal of the transistor T1, and therefore the node D1, being in this case at a low voltage. The voltage on the anode of the diode DI1 is far lower than the cathode voltage, i.e. than Vref, so that the diode will block the flow of current. Accordingly, the transistors Q11 and Q21 of the current mirror will be in the off state.

Thus, the diode DI1 functions as a blocking and triggering element, and is encircled by a dash line 31 in the Figure. Of course, this element 31 may be implemented in some other ways, provided that it will only supply current when the potential on its anode, or else on the node connected to the current mirror input, is significantly higher in absolute value than that on its cathode, but for the intrinsic voltage drop across the element 31 itself

The current mirror Q11–Q21 is generally shown at 41; it constitutes a preferential embodiment of the circuit means for generating the transistor T1 turn-on signal for recycling triggering. The turn-on signal consists in this case of the output current from the current mirror. In addition, the current mirror can optionally supply an amplified current.

If the voltage on the node D1 attains a fairly large value, the current mirror should be capable of operating at a high voltage, since it is connected to that node D1.

The circuit construction of the current mirror Q11–Q21 could be implemented in any other ways. Als , the transistors Q11 and Q21 are not required to be f the bipolar type, and the mirror may be implemented with MOS technology, for example. It is also not necessary that the mirr r be powered from just D1.

Additionally, the current mirror is not required for practicing the invention. The use of different circuit means is also encompassed by the invention, provided that they can supply a turn-on signal, typically a current or voltage, to the terminal DR1.

The active element T1 illustratively comprised of a MOS transistor could be replaced by a different active element, e.g. a Darlington.

Advantageously, the preferred embodiment shown in FIG. 6 of the recycling circuit 1, where the latter is advantageously in the integrated form, would occupy a greatly reduced area because it includes a reduced number of transistors, and a smaller area than the conventional circuits previously described.

The recycling control afforded by the circuit shown in FIG. 6 is advantageously unaffected by fluctuations in such external parameters as temperature and fabrication, because the values VmaxDn are mainly dependent on the voltage Vref, as previously explained. The contribution from the diodes DIn and the current mirror toward setting the value VmaxDn is a substantially stable one to temperature and unaffected by process parameters.

It should be understood that changes and modifications may be made unto the recycling circuit herein described and illustrated, within the scope of this invention as defined in the appended claims.

Having thus described at least one illustrative embodiment of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only, and not intended to be limiting. The invention is limited only as defined in the following claims and the equivalents thereto.

What is claimed is:

1. A circuit for recycling discharge current of an inductive load, the inductive load having a first terminal coupled to a first power supply terminal and a second terminal, the circuit comprising:
   - an active element having a first terminal coupled to the second terminal of the inductive load, a second terminal coupled to a second power supply terminal, and a control terminal that is responsive to a control signal; and
   - a regulator including:
     - a turn-on circuit having a first terminal coupled to the control terminal of the active element and a second terminal; and
     - a blocking and triggering element having a first terminal that receives a reference potential, having a second terminal that provides a turn-on signal to the second terminal of the turn-on circuit when a potential at the second terminal of the inductive load has a magnitude greater than a magnitude of the reference potential, so as to begin recycling of current through the active element and to discharge the inductive load, and having a diode that is forward biased to allow current flow through the diode when a potential at the second terminal of the inductive load has a magnitude that is greater than the magnitude of the reference potential.

2. The circuit of claim 1, wherein the turn-on circuit is powered from the second terminal of the inductive load.

3. The ~~circuit of claim 1, wherein the turn-on circuit~~ includes a current mirror having an input leg coupled to the second terminal of the blocking and triggering element and an output leg coupled to the control terminal of the active element.

4. The circuit of claim 3, wherein the second terminal of the blocking and triggering element is coupled to the second terminal of the inductive load through the current mirror.

5. The circuit of claim 3. wherein the current mirror further includes a supply terminal coupled to the second terminal of the inductive load.

6. The circuit of claim 1. further comprising a reference voltage generating circuit having an output that provides the reference potential so that the magnitude of the reference potential is substantially unaffected by temperature.

7. The circuit of claim 1. wherein the active element includes a MOS power transistor.

8. An integrated circuit comprising a plurality of circuits of claim 1. wherein the regulator of each circuit is coupled to a respective one of a plurality of inductive loads. each of the plurality of circuits controllably and independently recycling the discharge current of each of the plurality of inductive loads.

9. The circuit of claim 8. wherein each of the plurality of regulators has an input terminal that receives the reference potential.

10. The circuit of claim 1. further comprising:

a control circuit having an output that provides the control signal to the control terminal of the active element; and

an impedance device having a first terminal coupled to the control terminal of the active element and a second terminal coupled to the second power supply terminal.

11. A method for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the method comprising the steps of:

allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

controlling a discharge device to recycle the current from the inductive load in response to the control current;

blocking the control current when the voltage at the second terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude; and

wherein:

the step of allowing includes forward biasing a diode; and

the step of blocking includes reverse biasing the diode.

12. The method of claim 11. the method being further for controlling a discharge of current from a second inductive load having a first terminal coupled to the first voltage reference and a second terminal. the method further comprising the steps of:

allowing a second control current to flow from the second terminal of the second inductive load to the second voltage reference when a voltage at the second terminal of the second inductive load has a magnitude that is greater than the predetermined magnitude; and

controlling a discharge device to recycle the current from the second inductive load in response to the second control current.

13. A method for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the method comprising the steps of:

allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude:

controlling a discharge device to recycle the current from the inductive load in response to the control current;

blocking the control current when the voltage at the second terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude; and

wherein:

the step of allowing includes forward biasing a diode;

the step of blocking includes reverse biasing the diode; and

the step of controlling includes a step of mirroring the control current to provide an activation signal to activate a transistor. so that the transistor discharges current from the second terminal of the inductive load.

14. A method for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the method comprising the steps of:

allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

controlling a discharge device to recycle the current from the inductive load in response to the control current; and

wherein the step of controlling includes a step of mirroring the control current to provide an activation signal to activate a transistor. so that the transistor discharges current from the second terminal of the inductive load.

15. A method for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the method comprising the steps of:

allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

controlling a discharge device to recycle the current from the inductive load in response to the control current; and

wherein the step of allowing includes forward biasing a diode having a terminal coupled to a third voltage reference.

16. The method of claim 15. further comprising a step of maintaining a magnitude of the third voltage reference to be substantially independent of a variation in temperature.

17. An apparatus for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the apparatus comprising:

means for allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

means for controlling a discharge device to recycle the current from the inductive load in response to the control current; and

wherein the means for allowing includes means for blocking the control current when the voltage at the second terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude and a diode that is forward biased when the voltage at the second terminal of the inductive load has a magnitude

that is greater than the predetermined magnitude and that is reversed biased when the voltage at the second terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude.

18. The apparatus of claim 17. the apparatus being further for controlling a discharge of current from a second inductive load having a first terminal coupled to the first voltage reference and a second terminal. the apparatus further comprising:

means for allowing a second control current to flow from the second terminal of the second inductive load to the second voltage reference when a voltage at the second terminal of the second inductive load has a magnitude that is greater than the predetermined magnitude; and

means for controlling a discharge device to recycle the current from the second inductive load in response to the second control current.

19. An apparatus for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the apparatus comprising:

means for allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

means for controlling a discharge device to recycle the current from the inductive load in response to the control current; and

wherein:

the means for allowing includes means for blocking the control current when the voltage at the second terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude;

the means for allowing includes a diode that is forward biased when the voltage at the second terminal of the inductive load has a magnitude that is greater than the predetermined magnitude and that is reversed biased when the voltage at the second terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude; and

the means for controlling includes means for mirroring the control current to provide an activation signal to activate a transistor. so that the transistor discharges current from the second terminal of the inductive load.

20. An apparatus for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the apparatus comprising:

means for allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

means for controlling a discharge device to recycle the current from the inductive load in response to the control current: and

wherein the means for controlling includes means for mirroring the control current to provide an activation signal to activate a transistor. so that the transistor discharges current from the second terminal of the inductive load.

21. An apparatus for controlling a discharge of current from an inductive load having a first terminal coupled to a first voltage reference and a second terminal. the apparatus comprising:

means for allowing a control current to flow from the second terminal of the inductive load to a second voltage reference when a voltage at the second terminal of the inductive load has a magnitude that is greater than a predetermined magnitude;

means for controlling a discharge device to recycle the current from the inductive load in response to the control current; and

wherein the means for allowing includes means for forward biasing a diode having a terminal coupled to a third voltage reference.

22. The apparatus of claim 21. further comprising means for maintaining a magnitude of the third voltage reference to be substantially independent of a variation in temperature.

23. A circuit for recycling current from an inductive load through a control device that is coupled in series with the inductive load. the apparatus comprising:

a control circuit having a first terminal coupled to a control terminal of the control device and a second terminal;

a nonlinear device having a first terminal that receives a signal of a predetermined magnitude and a second terminal that provides an activation signal to the second terminal of the control circuit when a voltage at a first terminal of the inductive load has a magnitude that is greater than the predetermined magnitude. so that the control circuit controls the control device to recycle the current from the inductive load; and

wherein the nonlinear device includes a diode that is forward biased when the voltage at the first terminal of the inductive load has a magnitude that is greater than the predetermined magnitude and that is reverse biased when the voltage at the first terminal of the inductive load has a magnitude that is not greater than the predetermined magnitude.

24. The circuit of claim 23. wherein the control circuit includes a current mirror having an input leg coupled to the second terminal of the nonlinear device and an output leg coupled to a control terminal of the control device.

25. The circuit of claim 24. wherein:

the inductive load has a second terminal coupled to a first voltage reference;

the control device has a first terminal coupled to the first terminal of the inductive load and a second terminal coupled to a second voltage reference; and

the current mirror further has a power terminal coupled to the first terminal of the inductive load.

26. The circuit of claim 23. wherein the predetermined magnitude is a voltage of an input signal.

27. The circuit of claim 26. further comprising a voltage circuit that maintains the predetermined magnitude of the input signal to be substantially independent of a variation in temperature.

28. The circuit of claim 23. in combination with the inductive load and the control device.

29. The circuit of claim 23. the circuit being further for recycling current from a second inductive l ad through a second control device that is coupled in series with the second inductive load. the circuit further comprising:

a second control circuit having a first terminal coupled to a control terminal f the second control device and a second terminal: and

a second nonlinear device having a first terminal that receives the signal of predetermined magnitude and a second terminal that provides an activation signal to the

second terminal of the second control circuit when a voltage at a first terminal of the second inductive load has a magnitude that is greater than a predetermined magnitude, so that the second control circuit controls

the second control device to recycle the current from the second inductive load.